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SPRAY IRRIGATION--A LAND DISPOSAL PRACTICE
FOR DECONTAMINATING LEACHATE
FROM SANITARY LANDFILLS

U.S. Department of Agriculture
Science and Education Administration
Agricultural Research Results • ARR-NE-4 • September 1979

PREFACE

Solid waste disposal in sanitary landfills often leads to leachate drainage and potential pollution of water resources. Land disposal has been effectively used to treat sewage wastes, but no widely accepted technology has been developed for leachate decontamination. This publication reports results of studies to determine the feasibility of spray irrigation as a method of concentrating leachate wastes in forest and grassland ecosystems.

We appreciate the budgetary support of the Solid Hazardous Waste Research Division, Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and the assistance of the Southern West Virginia Regional Health Council, Inc. Virtually all of the staff of the U.S. Department of Agriculture, Science and Education Administration at Morgantown, W. Va., assisted with the project. Chemical analyses were performed by J. McGinnis, A. Dawson, and J. Harris, research technicians under the supervision of J. L. Hern, chemist. E. L. Mathias and P. E. Lundberg, agronomists, helped to install plots and collect samples. P. Tindilia, landfill technician, coordinated the irrigation schedule and assisted with sample collection and analyses.

Single free copies of this report may be requested from the USDA, SEA/AR, West Virginia University, Morgantown, W. Va. 26506.

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Science and Education Administration, Agricultural Research Results,
Northeastern Series, No. 4, September 1979

Published by Agricultural Research (Northeastern Region), Science and Education Administration, U.S. Department of Agriculture, Beltsville, Md. 20705

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SPRAY IRRIGATION--A LAND DISPOSAL PRACTICE FOR
DECONTAMINATING LEACHATE FROM SANITARY LANDFILLS

By H. A. Menser, W. M. Winant, and O. L. Bennett¹

ABSTRACT

Spray irrigation for land disposal of leachate from the Mercer County, West Virginia, Sanitary Landfill has been used effectively to decontaminate wastewater since 1973. Organic and elemental pollutants in leachate, applied in amounts ranging from 38 to 155 cm over 8 months, declined to generally acceptable levels without affecting soil permeability as water percolated through 60 cm of soil. Subsoil acidity declined as Ca and Mg moved in percolate through the soil. Manganese concentrations exceeded proposed water quality standards during intense irrigation but fell to acceptable levels during rest periods. Native deciduous trees and introduced forage grasses generally withstood leachate irrigations and tended to concentrate waste elements. Chlorides increased in most foliage while Fe, Mn, Na, S, and N usually were highest in early season growth. Tall fescue and reed canarygrass contained higher elemental levels than other grasses. All grasses persisted well except brome grass. Red maple, yellow poplar, black locust, and sassafras were leachate-tolerant trees, but sourwoods died. Cinquefoil, ground pine, and wild strawberry were eliminated and replaced by poison ivy, Virginia creeper, and wild blackberry. Soils retained Ca, Mg, K, Fe, and Zn in surface layers but Na, Al, and Mn were dispersed throughout the profile. Lime and phosphate fertilizers benefited forage grass establishment. Hazardous concentrations of potentially toxic heavy metals (Cu, Cr, Cd, Pb and Ni) were not detected at any time in soils, vegetation, or soil percolates. Noxious odor control and waste stabilization were important benefits of leachate aeration.

KEYWORDS: Aeration, grass ecosystems, lime, phosphate, soil "sinks," vegetation "sinks," waste attenuation, wastewater, water quality, wooded ecosystems.

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BACKGROUND

Each day, Americans discard nearly 8 lbs per capita of solid waste primarily at land disposal sites (Weiss 1974). The volume of municipal and industrial waste disposal on land was recently estimated to be 400 million tons (Schomaker 1977). The majority of these wastes are disposed of improperly at open dumps or poorly managed landfills.

A sanitary landfill is a recommended method for solid waste disposal because the systematic daily burial and compaction of refuse prevents or minimizes the environmental nuisances and risks associated with open dumps. The Resource Recovery and Conservation Act of 1976, PL 94-580, distinguishes a sanitary landfill from an open dump on the basis of there being no reasonable probability of adverse effects on health or the environment from disposal of solid waste at a sanitary landfill.

Percolation of water from within and through municipal sanitary landfills can lead to the formation of polluted leachate drainage into the surrounding environment. Leachate is defined as "liquid emanating from a land disposal cell that contains dissolved, suspended and/or microbial contaminants from the solid waste" (Metry and Cross 1976). Opinions may differ on the significance of leachate as an environmental risk because emotion often overrides the question (Ham 1975, Schomaker 1977). However, when air, soil, and water quality degradation follows the discharge of leachate into the environment, there can be little doubt about the pollution effect of this waste.

Leachate can be treated by biological, physical/chemical, or land application methods (Metry and Cross 1976); however, there is a scarcity of information, and virtually no guidelines exist on the actual use of specific practices. Soils and vegetation possess an almost infinite capacity to attenuate (decontaminate) organic and inorganic wastes. Spray irrigation is the principal technology for land application of liquid wastes but this method is limited by high land requirements, salt and toxic heavy metals accumulation in ecosystems, and aerosol movement. While spray irrigation has been used extensively to dispose of sewage effluents and food processing wastes (Pearson 1975, Sidle and Sopper 1976, Sopper and Kardos 1973), there is little experimental evidence showing the benefits and risks of spray irrigation for leachate treatment.

The Mercer County Sanitary Landfill, constructed in 1971 by the Southern West Virginia Regional Health Council, Inc. (SWVRHC), located along U.S. Route 460 between Princeton and Bluefield, is a solid waste disposal site for approximately 75,000 urban and rural residents (see figs. 1, 2, 3, and 4). Approximately 150 tons of weighed municipal solid waste, except sewage sludges, are deposited daily in a natural ravine in hilly terrain. Rodents and other nuisances are controlled by covering wastes with soil and subsurface shale obtained on site.

The U.S. Department of Agriculture, Science and Education Administration-Agricultural Research (formerly Agr. Res. Serv.) was requested by SWVRHC to provide technical advice on the disposal of leachate which had become an environmental hazard soon after the landfill opened. Cooperative studies, begun in

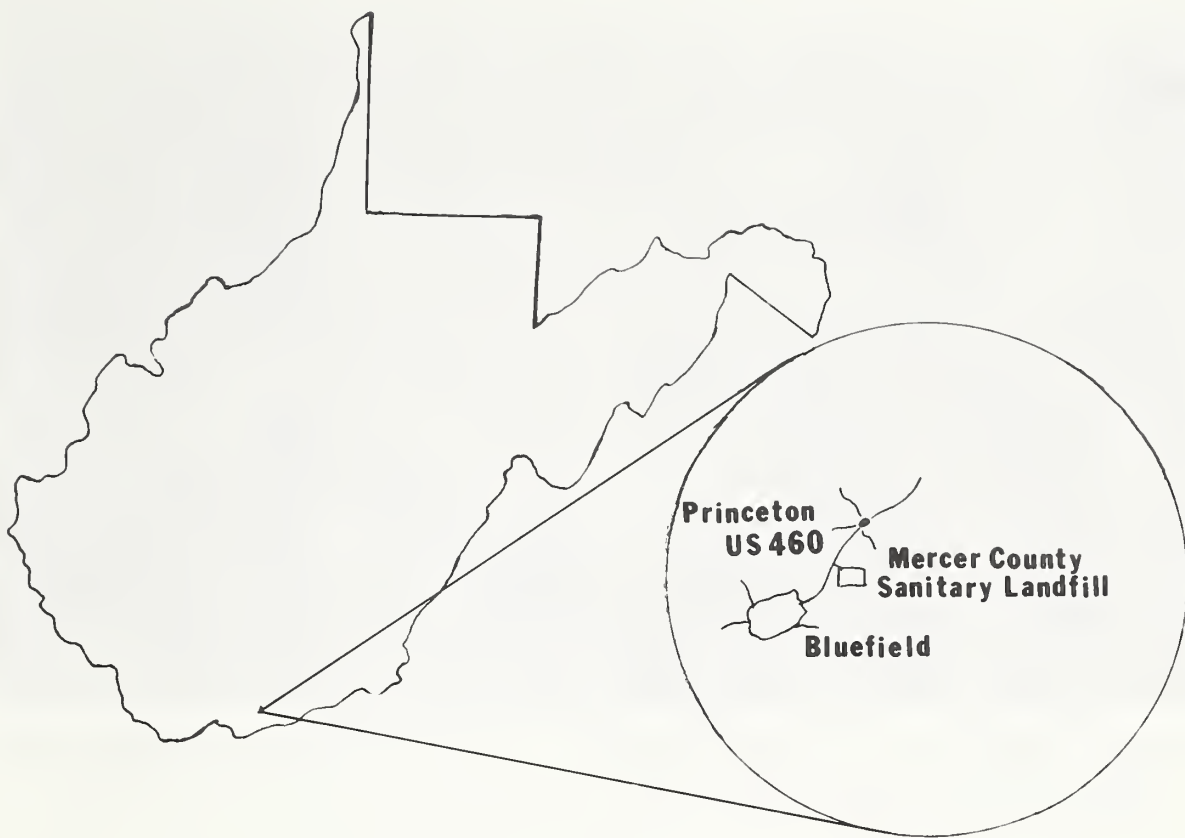


Figure 1.--Location of Mercer County Sanitary Landfill between Princeton and Bluefield, W. Va. Site of field study to determine the feasibility of land disposal as a method for decontaminating leachate wastewater.

1973, demonstrated the potential use of spray irrigation as a leachate treatment method (Bennett et al. 1975). Significant water quality improvement was obtained by using overhead rotary sprinklers to apply grossly polluted leachate to a small, wooded watershed; however, the complaints of nearby residents about noxious odors during irrigations ended this brief study.

A more remote site at the same landfill was chosen to continue spray irrigation treatments because initial studies appeared promising, and guidelines based on sustained leachate application had not been formulated.

OBJECTIVES

The basic objective of this project was to investigate safe disposal of landfill leachate by land application using spray irrigation as a management technique. Specific objectives were to determine:

1. The value of soils and vegetation as a system for upgrading water quality and concentrating pollutants, and, reciprocally, to evaluate the impact of leachate on forest and grassland ecosystems;



Figure 2.--Mercer County Sanitary Landfill. View of hilly terrain from ridge above landfill showing leachate catchment basin in center and refuse burial area in foreground.



Figure 3.--Refuse unloading and covering operations.

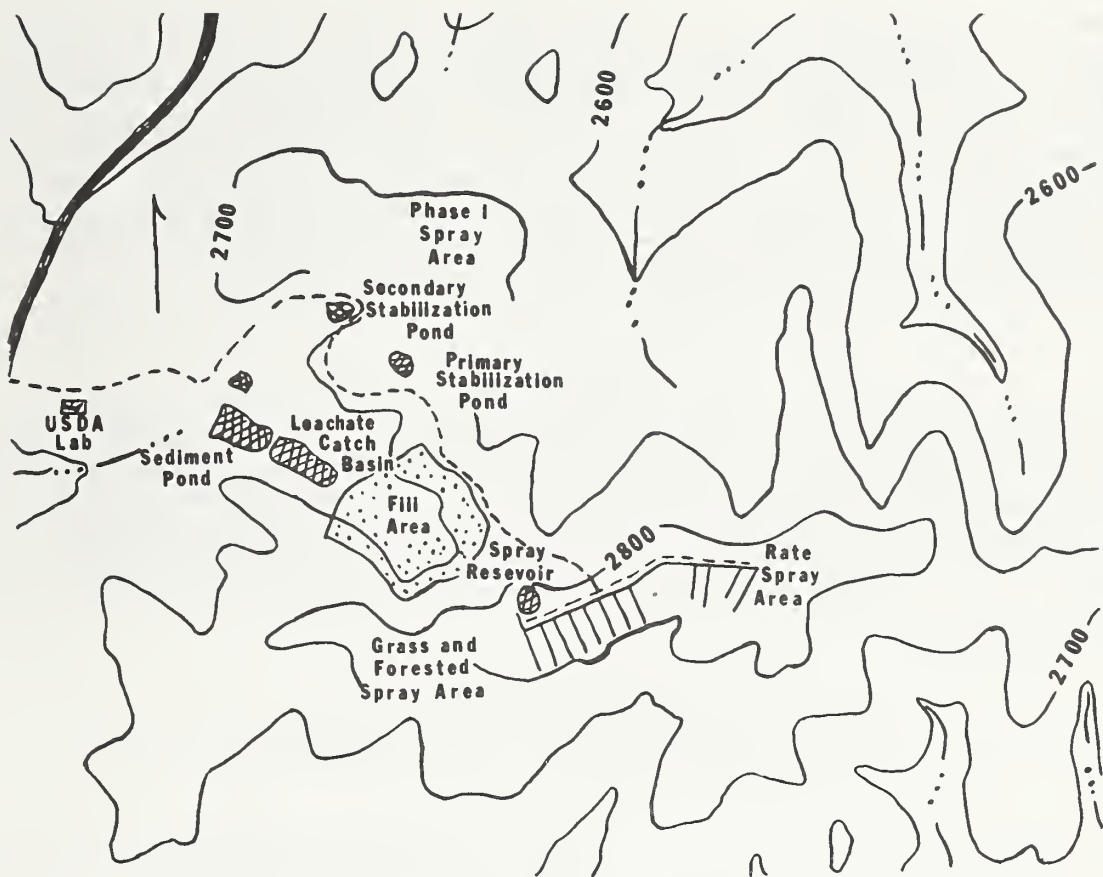


Figure 4.--Topographic representation of the Mercer County Sanitary Landfill showing principal features.

2. The role of soil amendments, including lime and phosphate fertilizers, as agents for promoting the filtrative capacities of soils and vegetation;
3. The effect of leachate irrigation rates on soil permeability; and
4. The feasibility of using aeration to stabilize wastes and control odors from leachate impoundments.

PROJECT OVERVIEW

Spray irrigation plots were established in 1974 in an abandoned pasture consisting of a 20-year succession of deciduous trees, shrubs, and ground covers. An adjoining area was cleared of native growth and seeded with several forage grasses. A surface aerator was installed in a catchment basin constructed to intercept subsurface leachate drains placed beneath the refuse burial area. Irrigation plots to measure the effect of application rates on soil permeability were established in 1976 in a second woodland succession area.

The principal features of the Mercer County Sanitary Landfill are shown in figure 4. Irrigation plots were situated along the crest of a ridge above the landfill. The surface aerator was operated in the leachate catch basin located at the toe of the landfill. Soils, leachates, soil percolates, and vegetation were tested for elemental composition before irrigations began and monitored for changes while studies progressed. Lime and phosphate fertilizers were scattered over the surface of wooded plots and before seeding forage grasses. Samples were analyzed in laboratories used by USDA at West Virginia University in Morgantown and in a mobile field station at the landfill.

PHYSIOGRAPHY

Marked variations in temperature and precipitation occur in West Virginia because of the rugged mountain and valley terrain. Winters are moderate to cold and summers are warm in the valleys and mild in the mountains. January and July temperatures in Mercer County average 0 °C and 21 °C, respectively. Precipitation is evenly distributed annually, totaling about 90 cm in the vicinity of the landfill. Precipitation records from 1972 through 1977 are shown in table 1.

Table 1.--Monthly precipitation record at the Mercer County Sanitary Landfill, 1972-77^{1/}

Month	Year and amount, cm					
	1972	1973	1974	1975	1976	1977
January	12.4	2.1	12.2	9.5	15.3	3.1
February	10.8	5.8	5.0	9.5	5.3	4.1
March	4.7	8.0	12.8	16.3	5.9	4.1
April	12.5	10.3	5.2	12.3	2.5	14.7
May	11.8	10.4	12.0	10.0	6.5	4.0
June	15.9	5.5	11.0	8.5	10.5	18.5
July	13.8	8.0	10.7	8.8	10.7	8.8
August	8.6	11.5	7.3	4.8	3.6	8.6
September	12.9	4.6	8.3	17.9	14.0	8.5
October	8.8	8.2	7.3	4.2	14.9	13.2
November	9.9	10.7	8.4	3.1	2.6	12.8
December	9.1	10.4	6.6	3.1	6.4	3.8
Total:						
Cm	130.2	95.5	106.8	108.0	98.2	105.2
Inches	51.9	37.6	42.0	42.5	38.7	41.4

^{1/}Data for 1972 and January through July 1973 obtained at the Bluefield Airport located approximately 8 km (5 mi) southwest of the landfill, and for December 1976 through March 1977 from the Princeton weather station located about the same distance north-northeast of the landfill.

Soil series within the leachate treatment area include Berks, Lily-Berks, Gilpin, Shelocta, Litz, Ernest, and Weikert. The first five series are fine loamy soils with inherent low fertility that developed in situ over a long time. All except the Ernest series usually are moist when there is no appreciable drought. Ernest soils are texturally similar to Berks and Gilpin but tend to be very wet with a firm hardpan 60 cm deep. Weikert soils are not as fully weathered as the others, are low in base saturation, and are underlain with bedrock at 50 cm. Geologic origins of the area date back to the Mississippian period of the Carboniferous Age. Parent materials consist of sedimentary sandstones and shales of the Bluestone Group and Mauch Chunk Series, respectively.

Topography, precipitation, and permeability of cover materials were key factors of concern in the generation of leachate. Water rapidly infiltrated through the shaly, porous cover, the refuse, and into subdrains placed beneath the landfill in anticipation of the problem. The interceptor drains emptied into a leachate catchment basin just below the fill area. Ditches were installed to direct surface runoff around the catchment basin into a sediment pond.

EXPERIMENTAL METHODS

Leachate Collection and Treatment System

Catchment and Aeration Basin

The catchment basin was constructed to collect and retain all leachate from subdrain and surface seepage (fig. 5). The 405,000 gal capacity was based on a 15 gal/min maximum leachate flow and 19 day retention. The flow rate varied from 5 to 20 gal/min since 1972 because precipitation has fluctuated widely. Natural, indigenous clay soil lined the catchment basin.

A Peabody-Welles surface aerator (FLTM Series, 20 hp, Aqua-Lator) was installed in 1974 to alleviate noxious leachate odors. Aeration also promotes stabilization (reduces pollutant potential) of inorganic and organic wastes formed anaerobically within the refuse and transported in the wastewater. The device, positioned near the center of the leachate catchment basin, causes a wavelike agitation which promotes oxidation of the leachate resulting in a reduction in noxious odors. Wastes are also stabilized by the formation of precipitable oxides. The system began operation in October 1974 on a schedule of 8 hours daily for 5 days a week.

Sediment Pond

A large sediment pond provided for settlement of solids collected by the flow of surface runoff in and around the refuse disposal area. This impoundment, located just below the leachate catchment basin, discharges into the Brush Creek Watershed.



Figure 5.--Leachate catchment basin, aerator, and sediment pond (background).

Spray Reservoir Pond

A spray reservoir, located on Big Ridge above and east of the landfill, was used for settling and stabilization of aerated leachate. Transfer of the effluent from the catchment basin to the spray reservoir was accomplished by using a 10 hp electric pump to lift the leachate 46 m over a distance of 385 m through galvanized pipe (5.1 cm diameter). The retention time of the spray reservoir is 32 days.

Spray Irrigation System

An overhead rotary sprinkler system was installed to apply leachate to wooded and grassy areas situated along the crest of Big Ridge above the landfill. Three application areas were established. For clarity, these areas are designated as (1) the woodland, (2) forage grass, and (3) spray rate studies (fig. 6).

The woodland study consisted of 16 adjoining plots, each 7.6 m on a side, situated on a Gilpin soil (Typic Hapludult, fine loamy, mixed, mesic) vegetated with an assortment of young deciduous trees, herbaceous shrubs, and ground



Figure 6.--Wooded (above) and forage grass (below) leachate treatment areas with overhead rotary sprinkler system in operation.

cover species. Four of the plots were treated with lime and four were treated with rock phosphate broadcast on the surface at 11.2 t/ha (metric tons per hectare). Another four plots received a surface application of 0.67 t/ha of superphosphate. The remaining four plots received no soil amendments. The plots were arranged in random design to minimize environmental bias. Rotary sprinklers spaced 6.1 m apart on 5 cm laterals 18.3 m apart, bisected and bordered the experiment. The laterals formed right angles with the 10 cm main irrigation pipeline. Application rates were measured by recording leachate found in small containers placed systematically in and around the plots. Foliage of five trees and one shrub, soil samples and soil percolate specimens at several depths were collected for baseline information in the fall of 1974 before irrigations began. Trees sampled included black locust (Robinia pseudo-acacia L.), red maple (Acer rubrum L.), sassafras (Sassafras albidum (Nutt.) Nees.), sourwood (Oxydendrum arboreum (L.) DC), yellow poplar (Liriodendron tulipifera L.), and the shrub was greenbrier (Smilax rotundifolia L.).

Adaptation to local conditions was a basic criterion for the selection of grasses to be tested for tolerance to leachate irrigation. Four of the grasses, namely, tall fescue (Festuca arundinacea Schreb.) cv. 'Ky 31', orchard-grass (Dactylis glomerata L.), bromegrass (Bromus inermis Leyss.) and reed canarygrass (Phalaris arundinacea L.) are classified as cool-season species noted for abundant growth in the spring and fall. Two bermudagrasses (Cynodon dactylon (L.) Pers.) cvs. 'Midland' and 'Tufcote' are warm-season types that thrive in hot, dry weather and persist well after they become established. The forage grass area was divided into six square blocks, each 12.2 m on a side. Each block was subdivided into 60 equal plots 3.1 m on a side. Applications of lime and phosphate fertilizers, at rates used in the woodland study, were broadcast in May 1974 and raked into Gilpin soil that had been cleared of native succession growth. Grasses were seeded or transplanted (bermudagrass) during the same month. Nitrate of soda (127 kg/ha) and superphosphate (115 kg/ha) were applied in July 1974 to promote the establishment and growth of grasses. Foliage, soil, and soil percolate samples were obtained from all plots during early September 1974. Irrigation pipe, overhead rotary sprinklers, and measuring containers were installed at spacings used in the woodland treatment area.

For studies of leachate application rates, enough suitable land was available for only two rates even though additional rates would have been desirable. Irrigation rates were 3- and 6-hour applications once a week from overhead rotary sprinklers installed to provide the most uniform coverage. Two areas on a uniform, gently sloping, wooded ridge about 500 m from the leachate spray reservoir were selected. The areas, 16 x 32 m each, were situated on Gilpin soil. Each of the two areas was subdivided into eight plots, 8 m on a side. Ground limestone (11.2 t/acre) was broadcast on the surface of four of the plots in the fall of 1975 before irrigations began. Lime was applied to help neutralize soil acidity and promote the beneficial action of soil microbes. Microbial action is essential to prevent the obstruction of soil pore spaces with wastes if soils are to be used effectively to attenuate wastewater. Soils, vegetation and soil percolate samples, and soil permeability measurements were obtained before applying leachate.

In all tests, leachate was applied at a rate of 0.64 cm/hr from sprinklers operated at a pressure of 35 lbs/in². The system was operated about 1 day a week in the woodland and forage grass areas.

Ecosystem Monitoring

During the project, soils were examined for leachate-induced changes by collecting small (0.2 cm) cores at depths of 0-5, 5-10, 10-15, 15-30, 30-45, and 45-60 cm. Changes in water quality were detected by analyzing percolate from suction cup lysimeters inserted to various soil depths (fig. 7). Vegetation was harvested in the spring after foliage emerged or during the summer as regrowth. Precautions were taken to avoid leachate contamination of leaves by collecting samples during irrigation rest periods. Leachate samples were taken from drains beneath the landfill as the leachate entered the catchment basin. Sprayed effluent samples were composites of the contents of small containers spaced in plots.

Soil permeability measurements were made by recording the infiltration rate of water placed in single ring, 1-m diameter infiltrometers (fig. 8).



Figure 7.--Ecosystem monitoring. Collecting soil percolate from suction cup lysimeter installed in forage grass plot irrigated with leachate.



Figure 8.--Installation of infiltrometer used to measure permeability of plots irrigated at weekly rates of 3 and 6 hours.

Analytical Procedures

All water samples were frozen immediately and stored at -20°C . Soils were air dried, pulverized, screened, and stored at room temperature in plastic screwcap vials. Leaves were dried in an oven at 60°C , ground in a Wiley cutting mill, and retained in sealed plastic bags.

The elemental concentrations of leachates and vegetation were determined spectroscopically after the samples were dissolved with heat and nitric acid: perchloric acid digestion. Elements measured by this method included calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), potassium (K), manganese (Mn),

strontium (Sr), zinc (Zn), aluminum (Al), cobalt (Co), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and cadmium (Cd). Total nitrogen (N) and total phosphorous (P) in leachates and foliage were also solubilized by strong oxidation, and concentrations were determined colorimetrically. Chlorides were extracted with dilute nitric acid and analyzed amperometrically. Direct spectroscopic analysis without pretreatment was used to determine elemental concentrations of soil percolates and soils extracted with dilute acids. Chemical oxygen demand (COD) and electroconductivity (EC), measures of oxidizable wastes and dissolved electrolytes in wastewaters, respectively, were determined by standard methods for water quality analysis. Soil and water acidity were measured with a pH meter. Procedural details for the various analyses are published elsewhere (Bennett et al. 1975, Menser et al. 1978, Menser et al. 1979).

EXPERIMENTAL OBSERVATIONS

Leachate Characteristics

Concentrations of nearly all leachate constituents were lower in sprayed effluent than in leachate collected from the leadfill drains entering the catchment basin (table 2). The decline in the levels of Fe and Mn in the catchment basin is probably due to aeration which would cause these elements to be converted from soluble to insoluble oxides and sulfides. Cadmium and Cr levels slightly exceeded the recommended tolerances for drinking water (Federal Register 1975), but Cu and Zn generally were less than the allowable limits (Federal Register 1977). Standards for Ni and Co have not been established. Heavy metal concentrations in leachate correspond with levels of the same elements in sewage effluent (Sidle and Sopper 1976). The gradual decline in COD followed the expected trend for this constituent as landfills age and wastes stabilize. Leachate data for the Mercer County Landfill generally agrees with other published leachate data (Chian and DeWalle 1976, Farquhar and Rovers 1976, Garland and Mosher 1975, Haxo 1976, and Metry and Cross 1976). Differences in concentrations among locations may be due to differences in sampling procedures.

Leachate loadings for woodland and forage grass ecosystems during the 1974-75 irrigation period were much greater than amounts applied later (figs. 9 and 10). Leachate contributed major quantities of elements essential for plant growth. These included Ca, Mg, K, N, and Cl; however, very little P was supplied. Iron and Mn quantities supplied by leachate greatly exceeded amounts needed as plant micronutrients.

Zinc applications measured about 35 kg/ha in the 1974-75 irrigations, and from 3 to 7 kg/ha at other times. Aluminum and Sr loadings were slightly less than for Zn. Lead, Cr, Ni, and Co rates were 1.5 to 2.5 kg/ha at the highest irrigation rates and less than 1 kg/ha at less than 100 cm of leachate. Cadmium and Cu never exceeded 1 kg/ha. The recycled value of essential plant nutrients in leachate, especially N, K, Ca, and Mg is important in light of the increasing cost of agricultural fertility units.

Table 2.--Chemical composition variations in sanitary landfill leachate (nonaerated and aerated) during spray irrigation testing, 1974-77

Element, ppm or parameter	Leachate source					
	Catchment basin (nonaerated)			Sprayed effluent (aerated)		
	1974-75	1975-76	1976-77	1974-75	1975-76	1976-77
Ca	728.6	892.7	235.4	426.3	326.8	250.0
Fe	415.9	647.0	157.1	201.4	84.3	76.8
Na	268.9	300.9	190.4	194.5	195.7	191.9
Cl	201.7	196.0		138.6	151.6	
Mg	143.9	164.2	53.9	90.2	87.1	67.7
K	113.5	120.1	232.4	80.9	84.3	93.1
Kjeldahl N	63.3	108.5	63.9	44.4	55.1	51.1
Mn	55.0	66.6	119.2	38.2	24.1	16.4
SO ₄	55.0	^{1/} --	--	65.0	--	--
Sr	2.60	2.65	3.47	1.69	1.37	1.03
Zn	2.58	1.51	2.09	2.38	.79	.87
Al	2.30	1.27	9.07	1.27	.58	.77
P	4.81	1.14	1.44	.39	.31	.58
B	--	1.89	.96	--	--	--
Co	.29	.37	.15	.30	.16	.23
Cr	.10	.35	.04	.09	.08	.05
Pb	.12	.37	.09	.09	.11	.07
Ni	.25	.25	.10	.17	.10	.09
Cu	.023	.034	1.032	.016	.013	.013
Cd	.016	.058	.011	.011	.015	.008
COD, mg/l	6805	8230	2485	4482	3213	2385
EC, μ mos/cm	4235	4772	2381	2895	2734	2267
pH	5.3	5.5		5.4	6.5	7.6

^{1/} -- Indicates no data.

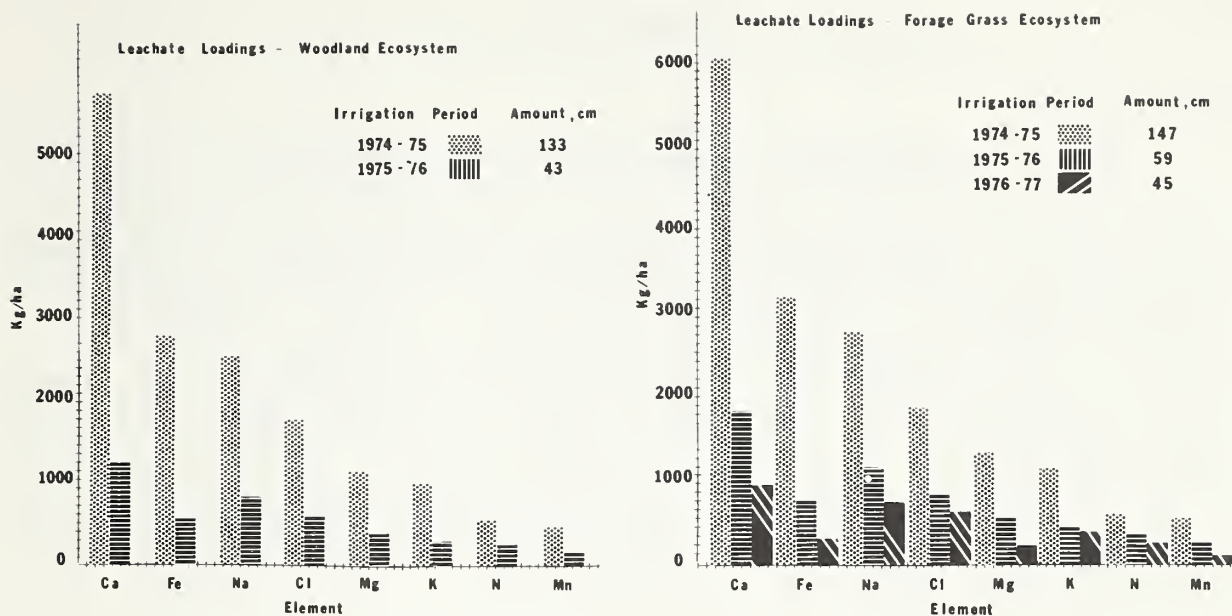


Figure 9.--Estimated amounts of various waste elements in leachate applied by spray irrigation to a deciduous woodland ecosystem (left) and a forage grass ecosystem (right).

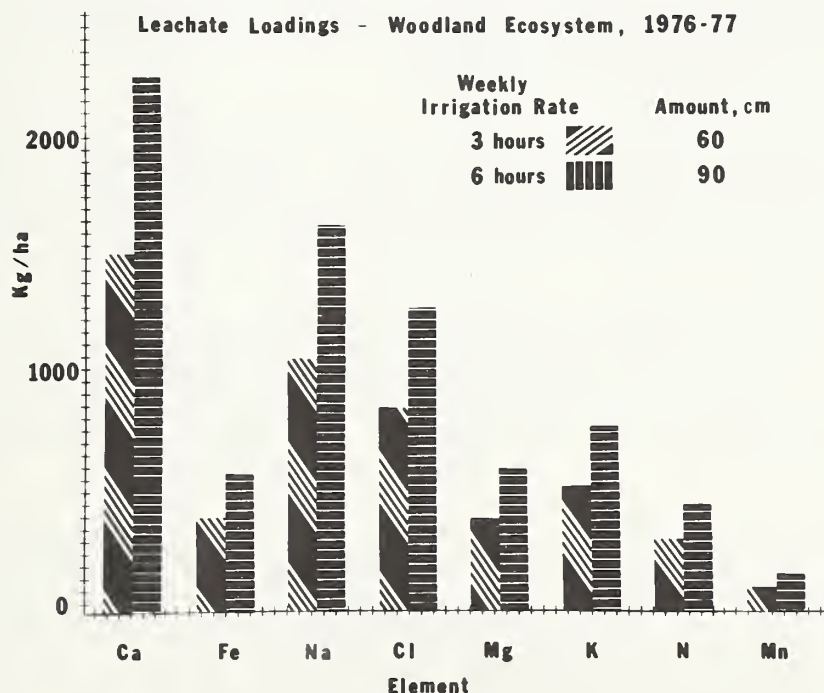


Figure 10.--Estimated amounts of various elements in leachate applied by spray irrigation at two rates to a deciduous woodland ecosystem.

Soil Percolate

Lime and P soil amendments did not appreciably affect the quality of soil percolates. For brevity, soil amendment data have been averaged to show changes and trends in water quality before, during, and after leachate irrigation (table 3). Concentrations of measured constituents increased immediately above baseline levels. Changes were evident at all depths indicating that dissolved substances were moving through the soil. Frequent samples were collected during the irrigation period that ended in May 1975 because the 133 cm of leachate applied during the previous 7 months was about three times greater than during the following year. Soils greatly diminished the concentrations of leachate wastes. Nearly all elements in soil percolates were below the maximum contaminant levels for public water systems. Calcium, Mg, Na, and K were well distributed within the 45 cm soil profile; however, soils retained Ca, Mg, and K more effectively than Na. The downward migration of Ca and Mg due to unknown causes may help to alleviate subsoil acidity and benefit the rooting depths of plants.

Manganese exceeded the proposed secondary maximum contaminant level for public water systems (Federal Register 1977) throughout the first irrigation season. We suspect that Mn was probably in a chemically reduced, soluble form which is not effectively removed by soils. Occasionally, Fe levels were slightly higher than allowable limits (Federal Register 1977); however, ecosystem removal of this element was highly efficient.

Toxic heavy metals including Cd, Cr, Pb, Cu, and Ni were below safe levels for primary drinking water systems (Federal Register 1975). Soils showed a strong capacity to remove Zn from solution.

Total N, P, SO_4 , and Cl were analyzed in raw leachates but none of these ions were prevalent⁴ in soil percolates. Best estimates suggest that total N, Cl, and SO_4 probably were less than 1 ppm each. Phosphorous is quickly complexed by soils and absorbed by plants. Nitrogen is converted to NO_3 and leached from the soil or absorbed by plants. Chlorides and SO_4 generally follow the same fate as N.

COD and EC of sprayed leachate showed major declines in soil percolates but there was no apparent relationship between soil depth and the concentrations of these constituents. Surface soil layers are important in diminishing the organic and inorganic wastes responsible for creating high COD and EC values in leachate.

Drought during the fall of 1975 led to a substantial decline in the leachate flow and, combined with freezing temperatures, delayed the next irrigation season until January 1976. Percolates collected in October 1975 near the midpoint of the 17-month irrigation rest period showed that concentrations of all soluble components had fallen significantly. Although the ecosystem demonstrated outstanding properties for removal of water pollutants, the need for rest periods is evident because some elements persisted at elevated levels.

Table 3.--Soil percolate composition before, during, and after spray irrigation of sanitary landfill leachate within a native hardwood ecosystem^{1/}

Depth, cm	Spray period	Date sampled	Element						Parameter		
			Ca	Mg	Na	K	Mn	Zn	COD	EC	pH
			Ppm						Mg/l	μMhos/cm	
0-15	Prespray 2/ 1st season-- 1st season 1st season 1st season Rest period/ 2nd season-- Rest period	7/5/74	9.38	1.38	3.15	2.22	1.16	0.06	824	129	6.09
		10/24/74	46.62	19.06	88.88	7.39	1.34	.02	340	770	5.96
		1/29/75	72.18	33.88	84.36	14.71	.84	.10	665	991	6.51
		3/19/75	55.27	23.81	69.80	10.84	2.28	.09	692	1058	7.39
		4/23/75	72.36	51.82	133.71	27.78	6.98	.39	954	1170	7.15
		10/22/75	36.00	16.00	56.21	5.08	.90	.04	43	494	6.92
		5/4/76	18.00	15.98	100.91	11.20	.04	.01	42	841	7.39
		10/21/76	13.78	10.12	54.62	10.58	3/—	—	39	452	7.04
15-30	7/5/74 10/24/74 1/29/75 3/19/75 4/23/75 10/22/75 5/4/76 10/21/76	8.25	3.12	3.45	.75	.36	.06	1474	97	6.10	
		34.00	9.42	61.57	7.25	2.05	.05	89	725	7.00	
		54.16	20.78	85.00	4.00	.92	.05	573	942	5.83	
		55.98	23.18	60.85	9.23	1.52	.10	571	1068	6.55	
		122.51	40.17	92.57	8.88	16.48	.17	1104	1443	5.82	
		10/22/75	52.74	16.75	85.36	4.68	—	—	36	462	6.88
		5/4/76	27.88	17.85	86.68	8.01	—	—	42	808	7.30
		10/21/76	48.36	17.12	105.25	6.59	—	—	48	1133	6.92
30-45	7/5/74 10/24/74 1/29/75 3/19/75 4/23/75 10/22/75 5/4/76 10/21/76	8.57	1.57	2.98	1.14	.68	.08	1510	106	6.06	
		46.00	14.33	62.50	2.51	2.61	.22	245	755	5.83	
		75.00	21.97	86.16	6.43	6.33	.06	540	722	6.06	
		71.59	23.00	63.94	8.55	3.30	.05	688	1156	6.88	
		113.17	29.90	93.58	8.71	20.70	.06	1229	1315	5.62	
		10/22/75	37.50	12.51	88.65	5.21	.04	36	444	6.88	
		5/4/76	20.28	7.86	64.62	2.86	.34	28	616	7.00	
		10/21/76	33.81	12.43	91.88	4.13	—	—	1097	6.64	

^{1/} Soil treatments of lime, rock phosphate, and superphosphate did not appreciably affect percolate quality when compared to no amendment and, therefore, have been averaged to facilitate data presentation.

^{2/} Quantities of leachate irrigated were 133 and 43 cm during the first and second seasons, respectively.

^{3/} -- Indicates insufficient sample.

Foliage Results

Tables 4 and 5 report levels of major and trace elements in the leaves of six forest species sampled in 1974 before irrigation (C) and in 1975 and 1976 after leachate applications (S). The effects of soil amendments on elemental composition of foliage are concealed within the averages; however, a review of Ca and P levels in the control foliage strongly suggests that no significant information has been lost. Phosphate fertilizers probably caused a gradual increase in P levels in black locust, greenbrier, sassafras, and yellow poplar. Considerable amounts of N and K in leachate may have led to the increase in these elements in black locust, sassafras, and yellow poplar.

Calcium levels in leaves showed only minor changes during two years of leachate irrigations. The lack of response to Ca is difficult to explain because this element was added to the soil in large amounts and was retained in the surface layer, even though some Ca may have leached through the soil in soluble forms. Leachate irrigation increased foliar levels of Mg in sassafras, sourwood, and greenbrier and of Cl in all species.

Leachate irrigation has almost eliminated sourwood trees from the forest ecosystem. Manganese and Al concentrations initially were highest in sourwood but gradually diminished. Sourwood thrives on acid soils, hence the name "sourwood." The gradual neutralization of soil acidity by leachate applications may have rendered unavailable the acid-soluble nutrients needed for sourwood survival. Excessive amounts of water also may have led to the decline of this species.

Heavy metals (Ni, Pb, Cr, Co, and Cd) in foliage were lower than in foliage collected from a forest treated with sewage effluents (Sopper and Kardos 1973). Although Zn loadings in leachate approximated sewage effluent, leaves showed no tendency to concentrate this element. Copper concentrations remained essentially unchanged. None of the heavy metal levels in leaves were environmentally hazardous. Vegetation monitoring to detect changes in waste-treated ecosystems can be useful if the possibility of distortions due to biomass dilution are recognized; however, accurate measurements of forest biomass are difficult to obtain.

Ecological Changes

Many undergrowth and ground cover species were eliminated by spraying and have not returned. The chief species that vanished were wild strawberry (Fragaria virginia L.), cinquefoil (Potentilla canadensis L.), and ground pine (Lycopodium planatum L.). Undesirable species proliferated after sustained irrigation. Principal among these were Virginia creeper (Parthenocissus quinquefolia L.), pokeweed (Phytolacca americana L.), poison ivy (Rhus radicans L.), wild blackberry (Rubus allegheniensis Porter), and fireweed (Epilobium angustifolium L.). Encroaching species varied in distribution throughout the irrigation area. Spray irrigation also eliminated the deep cover of leaf litter, perhaps because the nutrients and moisture supplied in leachate stimulated microbial activity. Waste elements applied to soils will ultimately become recycled in leaf litter. The ecosystem is not an infinite "sink" for wastes; thus, continued monitoring is essential to determine when hazards to the environment may become imminent.

Table 4.--Concentrations of major elements in uncontaminated foliage of hardwood forest species
spray-irrigated with sanitary landfill leachate^{1/}

Species	Location, (year) ^{2/}	Element									
		N	P	K	Ca	Mg	Cl	Mn	Fe	Al	
		Percent									
		Ppm									
Black locust	1974C	3/ 3.77cd	0.26bc	0.94h-j	2.07a	0.16f	0.02f	103.1i	134.2b-f	29.7de	
	1975S	3.59	.20cd	1.52e	1.76b	.23a-d	.22a-d	395.0d-g	156.5f	38.2c-e	
	1976S	4.75a	.37a	2.68a	1.77b	.21e	.19cd	160.6hi	95.5c-f	16.6e	
Greenbrier	1974C	1.96jk	.16cd	1.52e	.71g	.16f	.01f	462.1d	94.7f	45.6c-e	
	1975S	2.70fg	.16d	1.12gh	.74g	.22e	.02f	435.1de	316.4a	35.7de	
	1976S	2.89ef	.26bc	1.85d	.84fg	.17f	.11e	204.9hi	125.9c-f	16.7e	
Red maple	1974C	1.63i	.29b	.80i-k	.84fg	.20ef	.02f	619.3c	117.2d-f	82.9bc	
	1975S	2.60f-h	.18cd	.66k	.97d-g	.29c	.16de	405.1d-g	202.8b	61.4b-d	
	1976S	2.47gh	.17cd	.93h-j	1.15d-f	.28c	.19cd	299.4e-h	151.5b-f	82.8bc	
Sassafras	1974C	2.16ij	.80cd	1.52e	1.04d-g	.22e	.02f	425.6d-f	164.7b-e	67.6b-d	
	1975S	3.07e	.16cd	1.36ef	1.18de	.37a	.26ab	430.5d-f	187.4bc	45.9c-e	
	1976S	4.15b	.38a	2.44b	1.24d	.27cd	.23a-c	282.5f-h	99.6f	29.2de	
Sourwood	1974C	1.76kl	.21c	.74jk	.88eg	.19ef	.01f	1292.5a	129.9c-f	217.8a	
	1975S	2.33hi	.20cd	.70jk	.88eg	.30bc	.18cd	1023.5b	201.6a	196.4a	
	1976S	2.80eg	.21c	1.06gh	.86eg	.16f	.10e	347.7d-h	196.7b	96.3b	
Yellow poplar	1974C	1.91j-l	.17cd	.98fg	1.64c	.26cd	.01f	405.5d-g	113.1ef	232.4a	
	1975S	2.76e-g	.21cd	1.18g-i	1.86a-c	.32b	.22b-d	428.1d-f	177.2b-d	97.2b	
	1976S	4.03b-c	.27b	2.17c	2.01ab	.30bc	.28a	273.2gh	112.1ef	68.9b-d	

^{1/} Lime and phosphate fertilizers used as soil amendments have been averaged to facilitate presentation.

^{2/} 1974C = Plots limed and fertilized but not sprayed with leachate.

1975S = Plots limed and fertilized and sprayed for 7 months with 133.2 cm (52.4 in) of leachate.

1976S = Plots limed and fertilized and sprayed for 4 months with 43.4 cm (17.1 in) of leachate.

^{3/} Means shown in columns are not significantly different from each other (0.05 probability level) when followed by the same letter.

Table 5.--Concentrations of trace elements in uncontaminated foliage of hardwood forest species
spray-irrigated with sanitary landfill leachate^{1/}

Species	Location ^{2/} (year)	Element									
		Na	Sr	Zn	Cu	Ni	Pb	Cr	Co	Cd	
Black locust	1974C	3/24.2c	84.0bc	31.2cd	5.31h-j	3.34cd	1.78de	1.09a	1.09a	0.33b	
	1975S	25.0c	69.6c	11.5h	4.70h-j	3.13cd	4.75a	1.11a	1.11a	.29bc	
	1976S	27.5c	28.9ef	26.0c-i	8.21de	5.55ab	.38f	.01f	.01f	.01f	
Greenbrier	1974C	19.4c	21.7fg	41.5b	7.55d-g	3.93c	1.88d	.46de	.46de	.22c-e	
	1975S	34.0c	20.7fg	16.1gh	8.34c-e	2.92d	2.40d	.65c-e	.65c-e	.18e	
	1976S	247.0a	12.0e	20.5e-g	12.15b	3.55cd	.31f	.01f	.01f	.01f	
Red maple	1974C	17.8c	30.4ef	50.2a	6.55e-h	2.06e	2.46cd	.67c-e	.67c-e	.42a	
	1975S	20.6c	31.2ef	20.4e-g	3.94j	1.88e	3.76b	.56de	.56de	.33b	
	1976S	33.1c	20.8fg	21.0e-g	4.57ij	1.72e	.88ef	.01f	.01f	.01f	
Sassafras	1974C	21.7c	40.4de	41.0b	8.69cd	5.18cd	1.78de	.84bc	.84bc	.25cd	
	1975S	28.0c	41.6de	18.0f-h	8.77cd	3.52cd	3.72b	.80cd	.80cd	.25cd	
	1976S	35.5c	19.8fg	28.4cd	14.83a	3.30ab	.46f	.01f	.01f	.01f	
Sourwood	1974C	20.3c	22.2fg	32.3c	5.84g-i	5.14ab	1.84de	.84bc	.84bc	.31b	
	1975S	82.7b	25.9e-g	24.2d-f	6.02f-i	5.94a	3.36bc	.70c-e	.70c-e	.20de	
	1976S	89.8b	12.1g	25.5c-e	7.90d-f	4.87b	.88ef	.01f	.01f	.01f	
Yellow poplar	1974C	21.5c	102.7a	29.3gh	6.74b	4.74b	.63cd	1.02ab	1.02ab	.32b	
	1975S	21.1c	98.4ab	15.4c-e	3.82cd	3.82cd	.51de	1.13a	1.13a	.23c-e	
	1976S	29.8c	52.5d	26.7cd	3.15cd	3.15cd	1.19ab	.01f	.01f	.01f	

^{1/} Lime and phosphate fertilizers used as soil amendments have been averaged to facilitate presentation.

^{2/} 1974C = Plots limed and fertilized but not sprayed with leachate.
1975S = Plots limed and fertilized and sprayed for 7 months with 133.2 cm (52.4 in) of leachate.
1976S = Plots limed and fertilized and sprayed for 4 months with 43.4 cm (17.1 in) of leachate.

^{3/} Means shown in columns are not significantly different from each other (0.05 probability level) when followed by the same letter.

Changes in Soil pH

Soils became less acid after almost 2 years of leachate applications (fig. 11). The change was especially pronounced in the upper 30 cm of soil, but acidity also decreased at 45 and 50 cm depths. The abundance of Ca in leachate generally obscured the influence of lime on soil pH. Neutralization of soil acidity is beneficial to most vegetation because toxic elements are taken out of the soil solution and roots can penetrate deeper into favorable moisture zones. The potential environmental threat of most acid-soluble heavy metals also lessens as acidity decreases.

Effect of Leachate on Soil pH

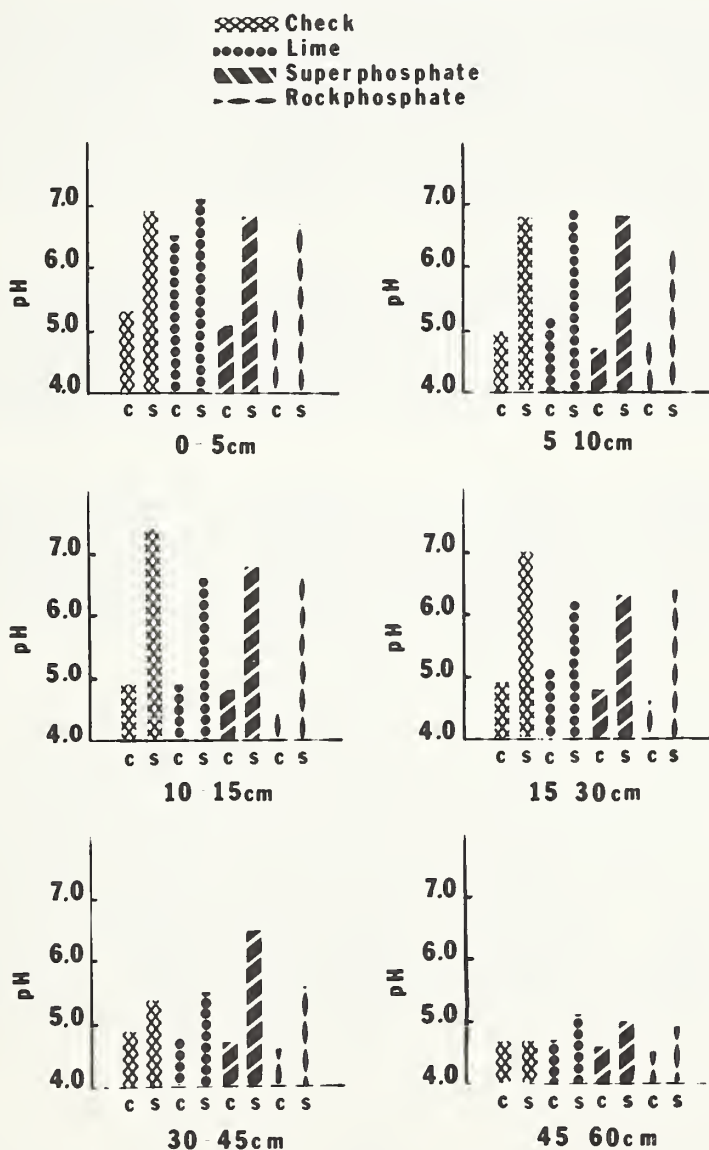


Figure 11.--Effect of leachate on soil pH: C, before irrigation; S, wooded ecosystem irrigated with 176 cm of leachate from October 1974 until June 1976.

Forage Grass Tests

Soil Percolate

Background water quality measurements made in late August 1974 showed very little influence of lime and phosphate amendments; therefore, data have been averaged to facilitate presentation (table 6). Calcium ranged between 3 and 10 ppm, Mg and Na between 1 and 2 ppm, and K, Mn, and Fe were less than 1 ppm. Samples contained small amounts of dissolved electrolytes and oxidizable products as reflected by EC and COD levels.

The first irrigations led to significant increases in concentrations of several constituents determined in soil percolates at four depths. These concentrations remained elevated through the first irrigation season (to 4/23/75) during which 147 cm of leachate was sprayed. Fifty-nine cm of leachate were irrigated in late 1975 and early 1976 and 45 cm in the fall and winter of 1976-77, but efforts to collect complete sets of water samples during these two irrigation seasons were prevented by freezing temperatures and limited soil moisture.

Water quality in late February 1977 did not differ greatly from that measured before leachate irrigation began in 1974. EC and COD levels probably declined as a result of the action of roots, microbes, and soil colloids on wastes or waste decomposition products. February samples reflected water quality shortly after the thaw of a severe winter when the system was down for 3 months.

Copper and Zn were the only toxic heavy metals reliably detected in soil percolates. Neither element was greater than the proposed secondary maximum concentration limit of 1.0 ppm for Cu and 0.5 ppm for Zn (Federal Register 1977). Lead, Cr, and Cd levels were environmentally acceptable in those soil percolates that contained the highest concentrations of other waste elements, notably Mn. Nickel levels were less than 1.0 ppm.

Lime lessened the acidity of soil percolates at all depths as shown by comparisons with percolates from P-treated and untreated soils (table 7). No major changes were noticed in the pH of soil percolate by October 24, 1974, except that acidity increased in percolates from untreated and superphosphate-treated soils. The temporary decline in the pH of many of these percolates may have been caused by the acidic properties of leachate in unbuffered soils. As irrigation progressed, there was a gradual neutralization of acidity at the upper, then lower, depths. The general trend of the 3-year trial showed that leachate caused an overall reduction in percolate acidity. The abundance of soluble Ca and Mg in leachate probably contributed to this change in acidity.

Forage Grass Composition

Elemental compositions of the six forage grasses before and after leachate irrigations appear in tables 8, 9, 10, and 11. Phosphate concentrations in all grasses were higher in soils initially fertilized with superphosphate as compared with lime, rock phosphate, and no soil amendment. Soil amendments

Table 6.--Soil percolate composition before, during, and after spray irrigation of sanitary landfill leachate on a forage grass ecosystem^{1/ 2/}

Depth, cm	Sampling date				
	8/22/74	10/24/74	3/19/75	4/23/75	2/25/77
Elemental concentration, ppm					
----- Ca -----					
0-15	8.3	63.8	111.3	75.5	8.1
15-30	7.6	57.8	89.4	93.0	7.5
30-45	2.8	44.6	62.2	54.5	10.0
45-60	3.3	33.8	47.3	37.6	8.0
----- Mg -----					
0-15	.8	17.3	25.1	23.0	3.8
15-30	1.6	16.6	19.6	20.4	2.6
30-45	1.4	14.9	14.8	15.1	3.6
45-60	1.2	13.4	12.4	11.1	3.2
----- Na -----					
0-15	1.4	155.2	52.4	58.8	68.5
15-30	2.2	137.4	50.1	55.2	37.3
30-45	1.6	116.2	35.9	40.8	47.9
45-60	1.9	99.4	29.2	29.1	35.6
----- K -----					
0-15	.6	6.0	25.2	6.6	2.0
15-30	.5	4.6	14.8	4.0	.9
30-45	.5	4.0	20.9	4.0	.6
45-60	.6	2.8	21.1	2.5	.5
----- Mn -----					
0-15	.12	5.87	26.89	21.21	.15
15-30	.24	5.42	15.08	23.22	.24
30-45	.25	5.66	12.30	12.15	.92
45-60	.29	4.71	8.31	10.10	.89
----- Fe -----					
0-15	<.08	.07	2.91	5.60	.02
15-30	<.08	.07	2.57	4.05	.02
30-45	<.08	.14	3.10	3.90	.12
45-60	<.08	.05	2.98	1.52	.14

See footnote at end of table.

Table 6.-- Soil percolate composition before, during, and after spray irrigation of sanitary landfill leachate on a forage grass ecosystem^{1/ 2/}--Continued

Depth, cm	Sampling date				
	8/22/74	10/24/74	3/19/75	4/23/75	2/25/77
Parameter level					
- - - - - EC, μ hos/cm - - - - -					
0-15	74	703	1045	1043	316
15-30	98	652	1004	880	337
30-45	71	534	650	608	226
45-60	73	453	717	493	266
- - - - - COD, mg/l - - - - -					
0-15	390	850	928	720	16
15-30	271	1027	938	708	16
30-45	210	881	618	406	15
45-60	474	811	457	456	14

^{1/} The first date was prior to irrigation. Leachate applications between the second and fourth dates totaled 147 cm. Adverse winter climate during 1975-76 and 1976-77 limited system operation to 3 months each season and applications of 59 and 45 cm, respectively. Samples collected the fifth date followed 9 month rest period.

^{2/} Data are averages of soils treated with no soil amendments and soils treated with either lime, rock phosphate, or superphosphate.

generally did not affect foliar elemental levels, except P. Thus, for simplicity, all data have been averaged. Cost factors ruled out the use of control forage plots irrigated with domestic water.

Liming and fertilization with N and phosphates are the probable causes for the relatively high levels of Ca, N, and P in foliage harvested in 1974 before leachate irrigations began. Nitrogen levels most often were highest in the first cutting and declined in the regrowth. This trend was apparent in most species after each irrigation cycle. Nitrogen supplied in leachate presumably caused the higher N levels observed in the early growth. Phosphorous levels generally declined from baseline levels and failed to show any consistent relationship to when grass was cut. The gradual increase in foliar Ca from 1974 through 1977 in the warm-season bermudagrasses as compared with the seasonal Ca fluctuations in cool-season grasses indicates a basic difference in the response of grass types to the heavy Ca loadings from leachate.

Table 7.--Effect of leachate application and soil amendment on the pH of soil percolate before and after spray irrigation of forage grass plots^{1/}

Sample depth, cm	Soil amendment	Sampling date				
		8/22/74	10/24/74	3/19/75	4/23/75	2/25/77
- - - - - pH - - - - -						
0-15	None	6.6	5.4	6.2	6.6	6.5
	Lime	6.8	6.8	7.1	6.7	6.3
	Rock phosphate	6.3	6.9	6.9	6.8	6.8
	Superphosphate	6.2	6.1	7.1	7.1	6.3
15-30	None	5.8	5.4	6.2	5.4	6.7
	Lime	6.4	6.1	7.2	4.2	6.4
	Rock phosphate	6.1	6.2	6.6	6.2	6.9
	Superphosphate	6.5	5.6	6.3	5.9	6.4
30-45	None	5.6	5.2	6.3	5.8	6.3
	Lime	6.1	6.0	6.5	6.2	6.4
	Rock phosphate	5.8	5.6	5.4	5.7	6.9
	Superphosphate	5.4	5.4	6.0	5.5	6.4
45-60	None	5.0	5.1	5.4	5.8	6.4
	Lime	6.1	6.0	6.8	6.4	6.3
	Rock phosphate	5.4	5.7	4.8	5.2	6.7
	Superphosphate	5.6	5.1	5.5	5.4	6.4

Depth, cm	pH	Amendment	pH
	\bar{x}		\bar{x}
0-15	6.5	None	5.9
15-30	6.2	Lime	6.4
30-45	5.9	Rock phosphate	6.2
45-60	5.7	Superphosphate	6.0

^{1/}Samples dated 8/22/74 were collected before the first leachate irrigation.

Calcium, Mg, K, and P levels were within reported ranges, but N concentrations, in all except bermudagrasses, exceeded the normal range (Miller 1958).

Bermudagrasses and brome grass exhibited lower Mg levels than other forages, but this element showed no tendency to accumulate in leaves as time progressed. Leachate led to significant increases in K content in the cool-season species but not in bermudagrasses. Sulfur was highest in leaves harvested shortly after the completion of the first year spray cycle.

Table 8.--Elemental composition of reed canarygrass spray-irrigated with sanitary landfill leachate during the fall, winter, and spring^{1/}

Element	Leachate irrigation period						
	1974	1974-75		1975-76		1976-77	
	Prespray	1st cut	Regrowth	1st cut	Regrowth	1st cut	Regrowth
----- Percent -----							
Total N	4.86	5.72	2.67	5.76	3.33	2.55	2.54
P	.38	.30	.24	.26	.46	.43	.25
K	1.38	2.67	1.89	3.54	3.41	2.72	2.28
Ca	.46	.28	.36	.25	.36	.42	.54
Mg	.25	.15	.24	.18	.23	.22	.29
S	.58	.80	.45	.26	.27	.26	.49
Cl	.19	.83	.89	1.24	2.41	1.68	1.18
----- Ppm -----							
Na	30.60	1765.70	29.60	55.30	40.50	108.00	13.80
Fe	86.50	670.50	103.20	101.10	138.00	96.40	54.40
Mn	321.50	573.50	79.20	218.30	379.80	225.70	272.90
Zn	33.80	52.60	33.00	45.60	38.70	32.80	43.70
Al	32.50	22.90	65.20	54.60	48.10	74.70	23.60
Cu	8.51	9.42	7.25	11.43	6.84	5.52	5.13
Sr	3.37	1.36	4.07	6.42	7.87	23.50	7.62
Cr	.44	.31	1.26	2.80	.10	.75	1.46
Ni	1.81	1.32	1.54	8.30	1.49	.61	1.92
Pb	1.47	1.01	2.99	1.16	.36	1.70	1.89
Cd	.08	.25	.14	.15	.25	.06	.01

^{1/}Amount of leachate irrigated, cm: 147 (1974-75), 59 (1975-76), 45 (1976-77).

Chloride levels in all species increased with irrigation, and reed canarygrass showed the biggest response to this highly soluble and mobile element. Species exhibited considerable variation in Na concentrations, ranging from less than 100 ppm in brome grass to 1700 ppm in reed canarygrass. Concentrations were highest after the first irrigation season. Unlike Cl, Na levels declined each year. Foliage contained more Na in the first cutting than in regrowth, probably because of higher concentrations in soils.

While Fe and Mn were applied to the forage ecosystem in large amounts, especially during the first irrigation season, species differed in the content of these elements. Reed canarygrass and Tufcote bermudagrass showed considerably higher levels of Fe than other grasses after the heavy loadings of the first irrigation season, but levels subsequently declined. Bermudagrass cultivars responded differentially to Mn. Concentrations of Mn in tall fescue

Table 10.--Elemental composition of bermudagrass cultivars, Midland and Tufcote, spray-irrigated with sanitary landfill leachate during the fall, winter, and spring^{1/}

Table 11.--Elemental composition of smooth brome grass spray-irrigated^{1/} with sanitary landfill leachate during the fall, winter, and spring

Element	Leachate irrigation period					
	1974 Prespray	1974-75 1st cut	1975-76 1st cut	1975-76 Regrowth	1976-77 1st cut	1976-77 Regrowth
----- Percent -----						
Total N	5.04	3.34	4.50	3.47	1.89	3.37
P	.36	.23	.22	.22	.13	.31
K	1.69	3.28	2.39	3.72	2.27	2.68
Ca	.45	.32	.34	.52	.24	.46
Mg	.17	.13	.14	.14	.12	.18
S	.45	.39	.24	.19	.17	.36
Cl	.14	.27	.20	.33	.87	.69
----- Ppm -----						
Na	23.80	58.00	81.30	49.80	95.00	15.60
Fe	90.00	140.80	98.20	154.80	52.10	66.20
Mn	135.00	544.20	144.10	223.10	76.00	156.50
Zn	27.90	37.20	25.50	27.40	26.50	28.40
Al	38.40	31.80	51.70	144.20	60.90	38.10
Cu	11.80	8.80	9.80	6.50	5.00	7.30
Sr	3.31	5.47	9.72	13.30	12.26	8.55
Cr	.53	.98	3.22	.10	.94	1.50
Ni	1.53	.94	4.22	.12	.52	1.10
Pb	2.38	2.14	1.13	.30	1.74	1.45
Cd	.16	.06	.16	.22	.07	.01

¹Amount of leachate irrigated, cm: 147 (1974-75), 59 (1975-76), 45 (1976-77).

in the first cutting (after the heaviest leachate application) greatly exceeded Mn concentrations in other cool-season species reported by Baker and Reid (1977), but levels decreased in subsequent harvests. Manganese did not cause any toxic symptoms in spite of the high levels.

No important changes in Zn, Cu, Al, and Sr levels of forages occurred during the 3-year term of this study. Among these elements, Zn was applied in the largest amount. Concentrations of the toxic heavy metals--Cr, Cd, Ni, and Pb--did not change appreciably from baseline levels determined in 1974 samples. Heavy metals in these forages would not be hazardous if consumed by grazing animals; however, our studies are not broad enough in the scope of all toxic metals to suggest that forages grown with recycled nutrients from leachate are safe for animal consumption. Technical details of the first-year forage grass studies appear elsewhere (Menser et al. 1979).

Persistence of Forage Grasses

Estimates of forage stands after 3 years of leachate applications show the influence of soil amendments and the importance of species selection (table 12). All soil amendments improved the tolerance of grasses to leachate, especially when applied during and after the first spray season when grasses were becoming established. Lime was the most beneficial treatment in achieving this result; however, Tufcote bermudagrass became established without lime or phosphates. Orchardgrass, reed canarygrass, and tall fescue stands were substantially depleted after the first spray season in all except lime-treated soils; however, all recovered very well (figs. 12 and 13). Bromegrass died out after the third season of leachate irrigations, but reasons for the death of this species are not apparent. Weed competition in the early summer of 1975 probably affected the elemental makeup and the persistence of grasses because severe infestations occurred in all species (Menser et al. 1979). The two bermudagrasses withstood leachate, weeds, and rigorous climate satisfactorily. Climatic adaptation would be an important criterion when choosing this species for treating wastes. Reed canarygrass was probably the best suited cool-season forage grass for persistence and concentration of waste elements.

Lime aided the establishment of grasses and promoted persistence after the heavy leachate irrigations of the first spray cycle. Superphosphate did not appreciably benefit grass persistence after the first irrigation season, but grasses grew more rapidly and showed larger yields (unpublished data) from soils treated with superphosphate.

Soil Analyses

Nearly all of the various quantities of elements applied in leachate were retained in the upper 5 cm of soil (figs. 14 and 15). Aluminum and Na tended to be more widely distributed throughout the soil profile. Extractable amounts of Ca, Mg, K, Zn, and Fe in the upper 10 cm of soil generally increased each year although leachate loadings declined during the same period. Manganese and Na levels were highest after the most sustained irrigation cycle (1974-75). Aluminum concentrations did not vary appreciably from baseline data except for increases in the upper 5 cm of soil.

Extractable amounts of P and the trace elements Sr and B increased in the upper 5 cm of the soil profile (table 13). Heavy metals Pb, Ni, Cr, Cu, and Cd also increased slightly and showed major retention in the superficial soil layer. Results suggest that the quantities of heavy metals applied to soils used in these studies would fall within environmentally acceptable limits and pose little risk to animal or human health.

Changes in Soil pH

The acidity of leachate-treated soil declined from an initial pH of 4.7 in the upper 5 cm to pH 6.5 after three irrigation seasons. The trend toward neutralization of acidity was apparent but less pronounced as soil depth increased (table 14). Organic acids probably cause leachate acidity, but the neutralizing properties of leachate are considerable. These acids presumably

Table 12.--Effect of sanitary landfill leachate on the survival of forage grasses spray-irrigated during the fall, winter, and spring (1974-77)^{1/}

Grass	Soil amendment and rate			
	Lime (11.2 t/ha)	Rock phosphate (11.2 t/ha)	Superphosphate (0.67 t/ha)	None
- - - - - Estimated stand, percent - - - - -				
Orchardgrass:				
1975	61	38	38	19
1976	85	80	68	46
1977	90	81	69	66
Reed canarygrass:				
1975	89	45	14	24
1976	98	90	71	70
1977	100	90	89	43
Bromegrass:				
1975	80	14	56	15
1976	79	61	84	48
1977	22	14	49	15
Tall fescue:				
1975	89	24	56	32
1976	71	71	59	68
1977	99	98	92	94
Midland bermudagrass:				
1975	50	50	44	31
1976	86	89	84	78
1977	92	86	71	91
Tufcote bermudagrass:				
1975	100	98	97	98
1976	98	100	95	97
1977	99	98	92	94

^{1/} Seasonal leachate application, cm

1974-75	147
1975-76	59
1976-77	45



Figure 12.--Effect of leachate irrigation on orchardgrass survival. Above, plots in early May 1975 after receiving 147 cm of leachate during the previous 8 months. Below, plots in June 1977 after dormant season applications of 59 and 45 cm of leachate during the previous 2 years.



Figure 13,--Effect of leachate irrigation on reed canarygrass survival. Above, plots in early May 1975 after receiving 147 cm of leachate during the previous 8 months. Below, plots in June 1977 after dormant season applications of 59 and 45 cm of leachate during the previous 2 years.

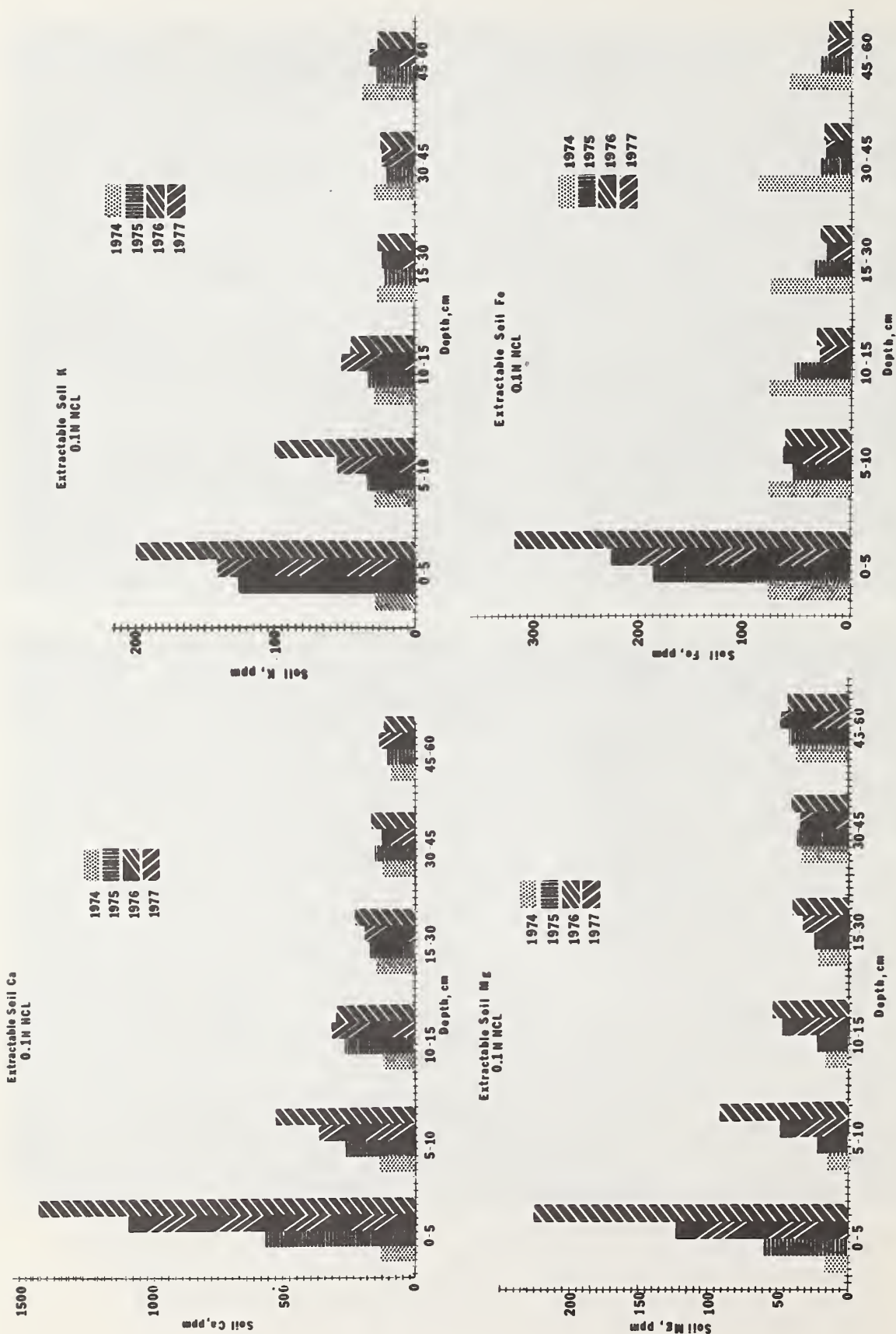


Figure 14.--Retention of waste elements by soils at various depths. Dilute acid extractable levels of Ca, K, Mg, and Fe after leachate irrigations of 147, 59, and 45 cm were applied to reed canarygrass during three dormant seasons. Baseline data were obtained in 1974.

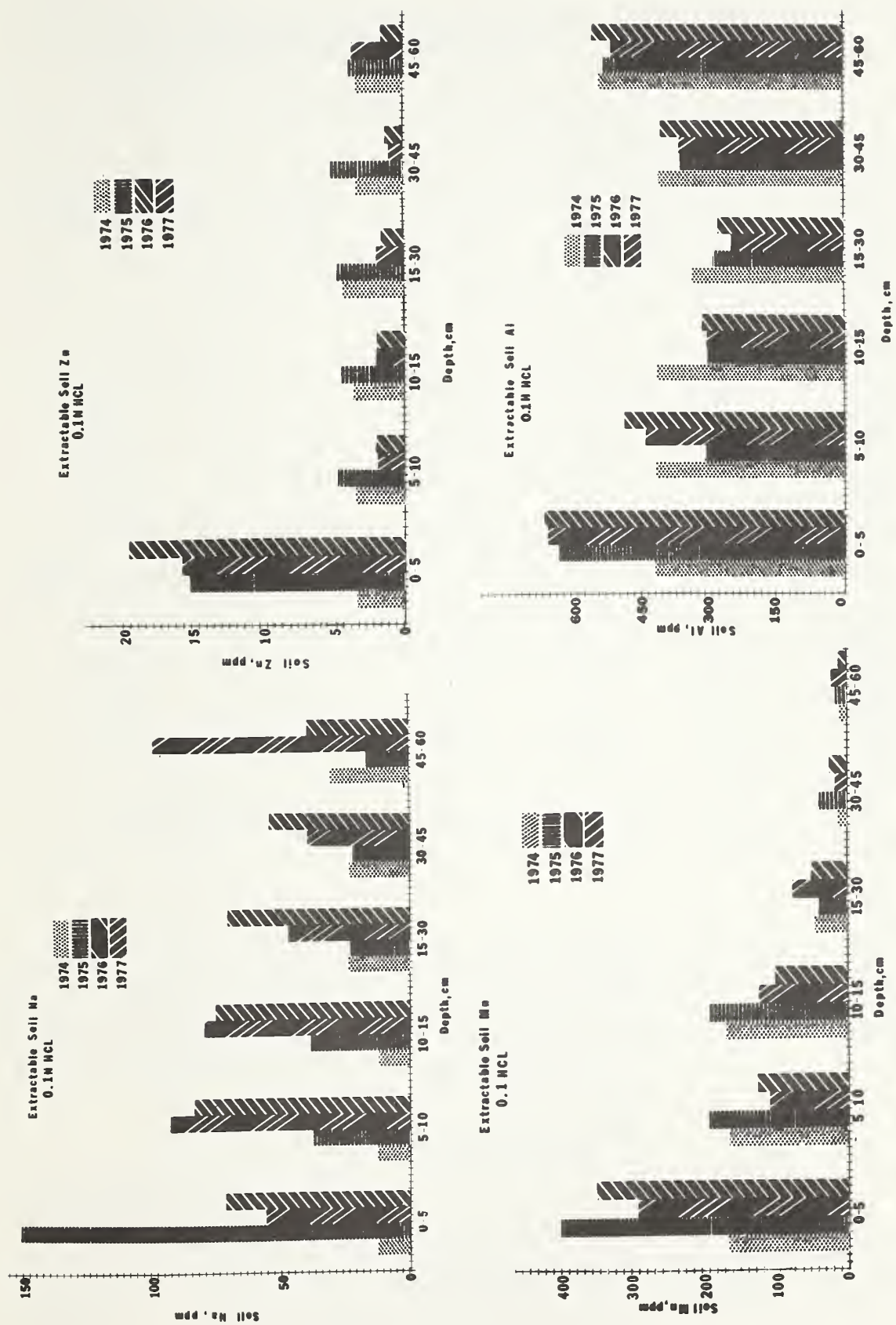


Figure 15.--Retention of waste elements by soils at various depths. Dilute acid extractable levels of Na, Zn, Mn, and Al after leachate irrigations of 147, 59, and 45 cm were applied to reed canarygrass during three dormant seasons. Baseline data were obtained in 1974.

Table 13.--Acid extractable concentrations of trace elements and heavy metals in soils irrigated over a 3-year period with leachate from a sanitary landfill

Element	Soil depth, cm														
	0-60 ^{1/}					0-5			5-10				10-60		
	1974	1975	1976	1977	Total	1975	1976	1977	Total	1975	1976	1977	Total		
----- Ppm -----															
P	3.00	260.00	450.00	254.00	964.00	5.00	22.00	7.00	34.00	3.00	3.00	2.00	8.00		
Sr	.80	9.10	17.00	17.30	43.40	1.40	3.40	3.10	7.90	1.10	1.30	1.30	3.70		
B	4.00	4.80	6.70	6.80	18.30	1.60	3.20	3.20	8.00	1.10	1.70	2.00	4.80		
Pb	4.20	9.10	7.60	7.20	23.90	4.60	5.00	5.10	14.70	4.20	3.70	4.30	12.20		
Co	1.10	3.30	3.90	4.20	11.40	1.40	2.10	2.00	5.50	.80	.80	1.00	2.60		
Ni	2.50	1.50	1.80	2.20	5.50	.60	1.20	1.90	3.70	1.40	1.00	3.20	5.60		
Cr	.36	.78	.97	.97	2.72	.20	.24	.27	.71	.19	.12	.15	.46		
Cu	.18	1.06	1.23	1.36	3.65	.40	.94	1.06	2.40	.33	.48	.53	1.34		
Cd	.21	.50	.51	.62	1.63	.15	.18	.28	.61	.16	.11	.23	.50		

1/Preirrigation data--average of all depths.

Table 14.--Changes in soil pH of forage grass plots established in 1974 with lime and phosphate fertilizers or no amendment and spray-irrigated for 3 years with sanitary landfill leachate, 1974-77

Forage species and soil depth, cm	1974 Pre- spray <u>1</u> /	After leachate irrigation			
		Soil amendment			
		None	Lime	Rock phosphate	Super- phosphate
		----- pH -----			
Reed canarygrass:					
0-5	4.7	6.9	7.1	6.8	6.8
5-10	4.7	6.4	6.5	6.6	6.4
10-15	4.7	5.7	5.4	5.9	5.5
15-30	4.3	5.1	4.9	5.2	4.8
30-45	4.3	4.6	4.6	4.7	4.5
45-60	4.3	4.4	4.6	4.5	4.4
Midland bermudagrass:					
0-5	4.7	6.4	6.6	6.3	6.6
5-10	4.7	6.3	6.5	6.2	6.5
10-15	4.7	5.6	5.7	5.7	5.9
15-30	4.8	5.3	5.0	5.1	5.4
30-45	4.6	4.9	4.8	4.7	5.1
45-60	4.5	4.9	4.5	4.8	4.8

1/One sample for 0-15 cm depth after land clearing and stump removal.

are degraded soon after application to the soil leaving an abundance of Ca, Mg, Na, and K. The passage of Ca and Mg through the soils should cause Al displacement, the reduction of H-ion production, and an eventual decline in excess soil acidity. This change would allow plants to develop more extensive root systems and would generally benefit growth.

Leachate Application Rates

Infiltration Results

Leachate applied at 3- and 6-hr/wk rates ranged in actual amounts (table 15). The variation occurred in one plot (No. 2) at the 3-hour rate and two plots (Nos. 11 and 13) at the 6-hour rate. A large pine tree in plot 2 obstructed the sprinkler pattern and biased accurate collection of leachate.

Table 15.--Average amounts of leachate applied to forested plots spray-irrigated for 2 years at rates of 3 and 6 hours a week^{1/}

Irrigation period	Leachate application, cm								\bar{x}
	Plot numbers for 3 hr/wk spray rate ^{2/}								
	1	2	3	4	5	6	7	8	
May 1976 through April 1977	63	38	64	61	56	73	63	56	60
July 1977 through March 1978	109	78	119	80	96	104	92	95	96
Total (2 yr)	172	116	183	141	152	177	155	151	156
	Plot numbers for 6 hr/wk spray rate ^{2/}								
	9	10	11	12	13	14	15	16	
May 1976 through April 1977	74	102	64	86	118	93	97	91	90
July 1977 through March 1978	159	164	160	160	161	164	161	160	161
Total (2 yr)	233	266	224	246	279	257	258	251	251

^{1/}As determined from containers placed in plots.

^{2/}Rate of spray irrigation was 0.64 cm/hr.

Irregular distribution in plots 11 and 13 was probably due to distortion of sprinkler patterns by tree trunks and foliage. Otherwise, amounts applied to each plot were reasonably equal at both rates in spite of the problems associated with obtaining reliable measurements. The average quantities of leachate applied to each plot were 156 and 251 cm respectively, for the 3- and 6-hour rates from May 1976 through March 1978. Virtually no leachate was irrigated during December 1976 and January-February 1977 because cold weather forced a system shutdown.

Infiltrometer readings taken periodically from May 1976 through March 1978 showed considerable variation on any date. The variation reflects differences in soil physical properties that might be encountered in a wooded ecosystem where rocks, roots, and other obstacles would interfere with percolation. Baseline data showed that infiltrative capacities of soils irrigated for 3 hours weekly were about one-third the rate of soils irrigated for 6 hours weekly (table 16). Comparative infiltration rates 22 months after irrigation began show only minor changes. This suggests that neither leachate rates nor liming appreciably affected soil permeability.

Soil Percolate Quality

Leachate irrigation caused immediate changes in the quality of soil percolates (table 17). The 6-hour irrigation rate resulted in slightly higher concentrations of Ca, Mg, Na, and K in the soil solution after 90 cm of leachate had been irrigated over a period of 15 months. Liming did not seem to affect the levels of Ca and Mg in irrigated soils, but liming alone led to

Table 16.--Comparative permeabilities of forest soils spray-irrigated with sanitary landfill leachate at 0.64 cm/hr for 3 and 6 hours a week from May 1976 through March 1978^{1/}

Leachate rate	Soil amendment	Infiltration rate, cm/hr		
		Pre-spray	Post-spray	Difference between soil treatments
3 hr/wk (156 cm)	None	3.9	7.1	0.2
	Lime (11.2 t/ha)	8.7	6.9	
6 hr/wk (251 cm)	None	27.5	19.0	2.5
	Lime (11.2 t/ha)	18.5	16.5	

^{1/}As determined from single-ring infiltrimeters installed in plots.

Table 17.--Effect of leachate application rate and lime treatment on the levels of various parameters in soil percolates after spray irrigation of a wooded ecosystem^{1/}

Element, ppm or parameter	Depth, cm	Prespray level at 0-45 cm depth	Postirrigation level					
			No lime			Limed at 11.2 t/ha		
			Leachate application, cm			Leachate application, cm		
			0	60	90	0	60	90
Ca	0-15	1.0-5.0	1.0	14.2	30.3	5.2	19.2	21.3
	15-30		1.4	11.0	25.0	2.5	11.4	30.1
	30-45		1.7	10.9	14.8	3.2	12.1	13.3
Mg	0-15	.1-1.0	.4	9.5	26.3	1.3	7.3	5.1
	15-30		.5	4.2	9.5	1.1	3.1	15.2
	30-45		.7	5.8	7.4	1.1	5.3	5.9
Na	0-15	.5-5.0	42.5	46.5	95.6	28.0	61.4	76.8
	15-30		47.2	40.0	86.0	20.8	52.0	92.6
	30-45		20.5	46.5	80.0	18.5	46.0	82.2
K	0-15	.5-1.5	.2	5.2	2.4	.4	4.5	4.6
	15-30		.1	1.2	7.0	.1	1.4	10.9
	30-45		.1	2.0	4.1	.1	1.3	1.9
Mn	0-15	.01-5.0	.02	.47	.04	.02	.19	.02
	15-30		.02	.34	.12	.02	.21	.35
	30-45		.02	.56	1.33	.02	.32	1.30
Zn	0-15	.01-0.1	.04	.04	.05	.06	.06	.04
	15-30		.04	.04	.04	.07	.03	.05
	30-45		.05	.05	.07	.04	.04	.05
EC μmhos/cm	0-15	15-100	40	444	966	52	486	707
	15-30		40	308	714	34	328	752
	30-45		60	312	592	44	322	486
COD mg/l	0-15	10-70	14	11	48	33	6	12
	15-30		13	17	22	12	16	38
	30-45		10	29	18	10	16	25
pH	0-15	5.6-6.5	6.4	6.6	7.7	6.9	6.9	7.4
	15-30		6.4	6.7	6.2	6.9	6.9	7.8
	30-45		6.4	6.2	6.4	6.8	6.9	7.4

^{1/}Prespray samples were obtained 4/29/76. Postirrigation samples were obtained 7/12/77 at the end of a 3-month rest period between the first and second spray cycles. Leachate was applied for 3 and 6 hours a week in total quantities of 60 and 90 cm, respectively.

small increases in concentrations of these elements. Irrigation promoted the downward movement of Ca and Mg. Sodium mobility was apparent at all depths at all times regardless of treatment. Concentrations were highest at the 6-hour irrigation rate. Potassium concentrations increased following irrigation but the changes generally would have little influence on water quality for domestic use. Manganese exceeded the proposed Secondary Maximum Contaminant Level (SMCL) of 0.05 mg/l for this element, but concentrations were considerably less than in percolates from grassland and other forested ecosystems in this study.

Trace elements Zn, Cu, and Fe showed no appreciable increases after irrigation. None of these elements exceeded the limits required for acceptable water quality. Toxic metals Pb, Cd, and Cr were less than the 0.025 ppm detection limits for multielement solutions.

Foliage Composition

Aluminum and Mn concentrations declined sharply in sourwood leaves irrigated with leachate but red maple and sassafras did not exhibit this tendency (fig. 16). Sourwood also showed lower Ca and Mg levels after leachate irrigation while Mg increased and Ca changed very little in red maple and

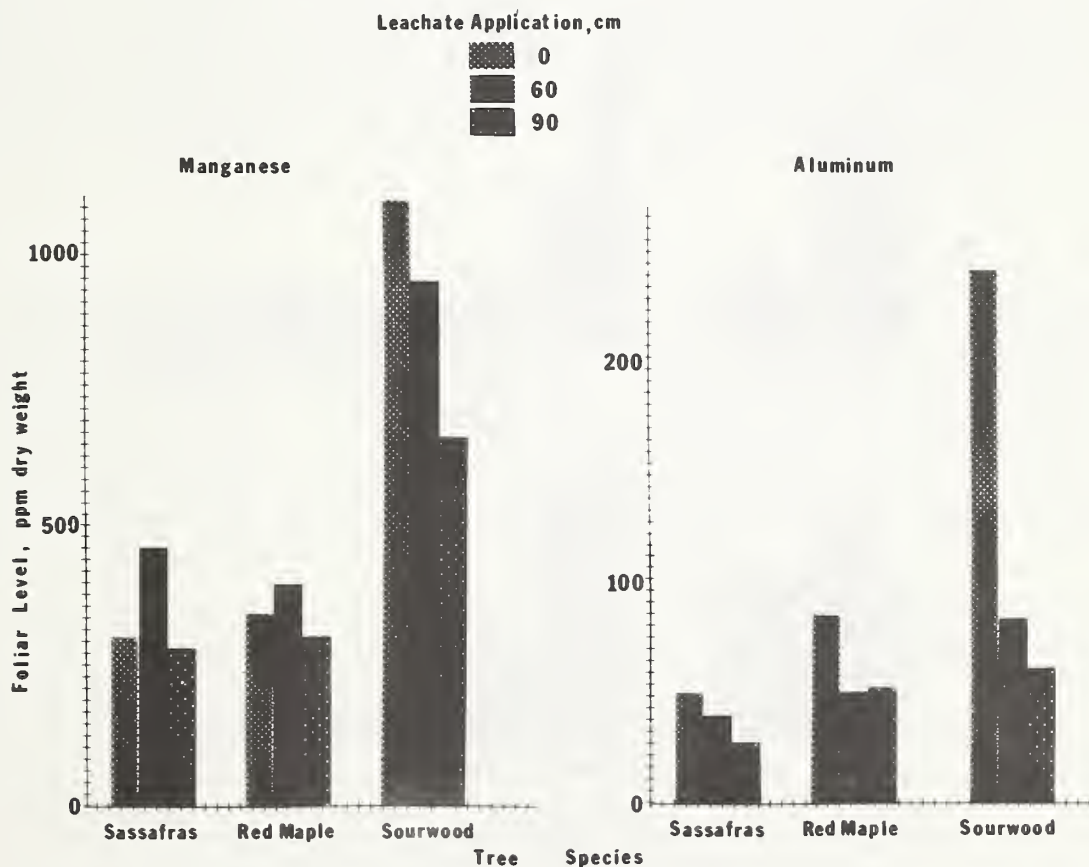


Figure 16.--Changes in Mn and Al concentrations in the foliage of three hardwoods irrigated with landfill leachate at weekly rates of 3 hours (60 cm) and 6 hours (90 cm) for 15 months.

sassafras (fig. 17). Sourwood may nutritionally require Mn at relatively high levels and apparently can absorb and tolerate Al at concentrations that would be toxic to other species. The substantial amounts of Ca and Mg added to soils in leachate tend to neutralize excess soil acidity and may have led to a decrease in availability of Al and Mn. Potassium levels were highest in sassafras.

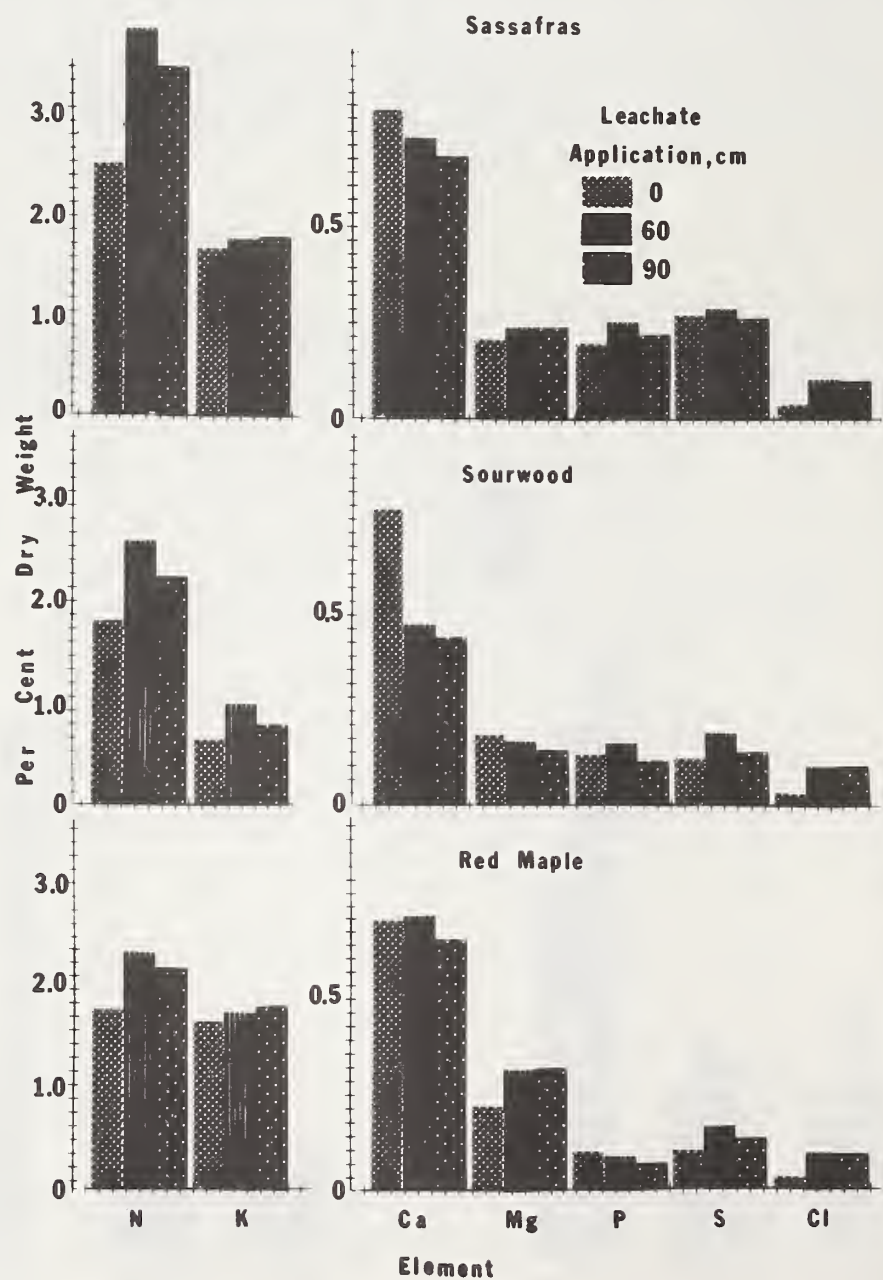


Figure 17.--Concentrations of major, essential plant nutrients in hardwood foliage spray-irrigated with leachate from a municipal sanitary landfill at weekly rates of 3 hours (60 cm) and 6 hours (90 cm) over 15 months.

Species differed in levels of Cu and Ni. Sassafras contained highest concentrations of Cu while red maple showed the lowest Ni levels. The 6-hour irrigation rate resulted in lower levels of Cd, Pb, and Cr in sourwood and Zn in red maple. Cadmium in the three hardwoods exceeded the suggested 0.5 ppm safety threshold for animal consumption; however, this vegetation is unlikely to be consumed by animals. Heavy metal additions to the ecosystem from leachate irrigation did not appear to be an environmental risk to wildlife.

Leachate caused about the same changes in ecological associations as we have previously discussed. Ground pine, cinquefoil, and wild strawberry were eliminated, a few succulent grasses and pokeweed increased, and young poplar, sassafras, and red maple trees withstood leachate residues on trunks and branches. Wild blackberry, poison ivy, and Virginia creeper became more prevalent.

Soil Analyses

Soil analyses show direct relationships between elemental concentrations and leachate rates (table 18). Lime caused substantial increases in acid extractable Ca but did not appreciably affect extractable amounts of other elements. Irrigation caused a small increase in Ca levels at the 15 to 30 cm depth but the source and cause of this change is unknown. Most elements were retained in superficial layers (0 to 5 cm); however, Na and Al were distributed within the first 30 cm. Lime and leachate immobilized Zn while Cr, Cd, Ni, and Cu concentrations suggested no potential toxic metal hazards.

Aeration of Leachate

Leachate samples were collected infrequently during the 3 years prior to installation of an aerator and USDA participation in leachate treatment studies at the Mercer County Sanitary Landfill. Enough samples were obtained during this period, however, to provide some indication of leachate composition before aeration began. Samples were collected more systematically after the aerator was installed. No major problem arose during the first year of aerator use. The system operated 8 hours daily, 5 days weekly from October 1974 until early 1976 when cold temperatures froze the surface of the catchment basin and forced a 6-week shutdown of the system.

Results of analyses for a period of nearly 2 years show that levels of all waste parameters were lower in leachate that had been aerated as compared with leachate sampled before aeration (table 19). As landfills age, solid waste stabilizes, and oxygen requirements for leachate diminish (Chian and DeWalle 1976). Aeration also promotes stabilization by furnishing the oxygen necessary for microbially mediated breakdown of organic wastes and by converting the soluble, reduced states of Fe and Mn to oxidized precipitates. The aerator was installed to alleviate noxious odors that had become a community nuisance. Aeration clearly achieved this objective.

Table 18.--Dilute acid extractable soil analyses from a forested ecosystem spray-irrigated with leachate from a municipal sanitary landfill

Element	Soil depth, cm	Leachate irrigation rate		
		None	3 hr at 0.64 cm/hr	6 hr at 0.64 cm/hr
			(total of 60 cm)	(total of 90 cm)
			Ppm	
Ca	0-5	2143	2961	4689
	15-30	170	262	348
Al	0-5	548	588	576
	15-30	422	430	364
Na	0-5	24	140	686
	15-30	20	118	154
K	0-5	56	192	192
	15-30	32	64	90
Mg	0-5	62	305	394
	15-30	12	65	81
Mn	0-5	82	210	308
	15-30	24	28	30
Fe	0-5	14	40	46
	15-30	16	18	16
Sr	0-5	3.6	8.1	11.6
	15-30	.8	1.4	1.9
Pb	0-5	7.2	7.2	8.4
	15-30	3.3	2.6	2.7
Zn	0-5	9.4	2.4	3.6
	15-30	1.2	.1	.1
B	0-5	.6	4.0	4.5
	15-30	.2	1.2	.9
Ni	0-5	2.2	1.8	2.5
	15-30	2.0	1.4	1.4
Cu	0-5	.70	.55	.88
	15-30	.51	.61	.57
Cr	0-5	.38	.92	1.02
	15-30	.26	.58	.67
Cd	0-5	.28	.42	.62
	15-30	.16	.22	.32

Table 19.--Effect of aeration on concentrations of various leachate parameters, 1971-76

Element, ppm or parameter	Leachate source		
	Catchment basin influent drains	Sprayed leachate	
		Nonaerated	Aerated
Ca	711	648	469
Mg	140	138	94
Fe	468	621	160
Mn	60	80	32
K	98	57	82
Na	271	327	212
Cl	200	450	140
N	82	65	51
Sr	2.4	2.8	1.6
Zn	2.7	9.1	1.7
Al	4.1	3.9	1.0
COD, mg/l	6185	9190	3748
EC, μ mhos	4023	4766	2774

CONCLUSIONS

Land disposal of solid waste will continue to be an important social and economic problem until new technologies for waste recovery make the practice impractical. The use of prime land for waste burial is economically unfeasible. Guidelines to protect water resources from leachate and to insure compliance with environmental quality standards generally are few and untested.

The spray irrigation method for land disposal of leachate from the Mercer County Sanitary Landfill has been an effective system for leachate decontamination since 1973. Grossly contaminated water applied at rates that did not cause runoff to wooded and grassland ecosystems showed significant reductions in organic and elemental pollutant levels after percolation through 60 cm of soil. Soils showed no important loss in permeability after 156 and 251 cm of leachate were irrigated over a 2-year period at weekly rates of 3 and 6 hours, respectively, at irrigation rates of 0.64 cm/hr.

Leachate irrigation resulted in the movement of Ca and Mg into the soil and the reduction of excess soil acidity. A decline in excess subsoil acidity should favorably affect plant growth by promoting deeper root penetration to sources of moisture and nutrients.

Manganese levels in soil percolates exceeded recommended maximum levels for drinking water during periods of sustained irrigation; however, levels of

toxic metals did not violate water quality standards. Manganese contamination of water usually diminished when irrigation was suspended or when leachate was applied less intensively.

Native trees and cultivated forage grasses generally tolerated leachate applications; however, some changes were apparent. Sourwood and bromegrass eventually disappeared from the ecosystem and many woodland ground cover and understory species were eliminated. Such undesirable species as poison ivy, Virginia creeper, and wild blackberry encroached in these areas. Stands of reed canarygrass, orchardgrass, and tall fescue were substantially depleted after 155 cm of leachate were irrigated over an 8-month period; however, recovery of these grasses was excellent during the next 2 years under less intensive irrigation. Bermudagrasses withstood leachate applications acceptably. Species adaptation should be considered in choosing forage grasses for wastewater renovation.

Native and cultivated ecosystems tended to concentrate waste elements in vegetation and soils; however, leachate loadings caused no heavy metal contamination of these sinks. Species differed considerably in concentrations of elements. Chloride levels increased appreciably in nearly all foliage. Iron, Mn, Na, S, and N levels usually were highest in grasses harvested early in the growing season and lowest in the regrowth. Tall fescue and reed canarygrass tended to contain higher elemental levels than other species. Manganese, Al, and Fe levels in sourwood foliage declined after leachate applications suggesting that this species was sensitive to pH-dependent changes in the availability of these elements. Extractable levels of Ca, Mg, K, Fe, and Zn were highest in the upper 5 cm of soil but Na, Al, and Mn were more equally distributed throughout the 60-cm profile. Concentrations of those elements that were retained in surface layers increased with time; however, levels of the more mobile elements showed a positive relationship to leachate loading rates.

Lime supplied significant quantities of Ca to soil, but the Ca-supplying power of leachate exceeded that of lime. Lime and phosphate fertilizers aided the establishment of grasses; however, the economic feasibility of using these amendments in wooded ecosystems is questionable unless loading rates of toxic heavy metals are excessive.

Noxious odor control and waste stabilization were important benefits of leachate aeration. Community relationships improved with the alleviation of objectionable odors. Aeration decreased the concentrations of leachate pollutants and stabilized wastes by causing the conversion of soluble and suspended components to precipitable forms or to odorless gases. Aeration pretreatment would increase the potential capacity of an ecosystem to attenuate leachate.

Spray irrigation appears to be an acceptable alternative for treatment of leachate from municipal solid waste landfills. Long term studies would be necessary to determine the ultimate limitations of this land disposal method for wastewater renovation.

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